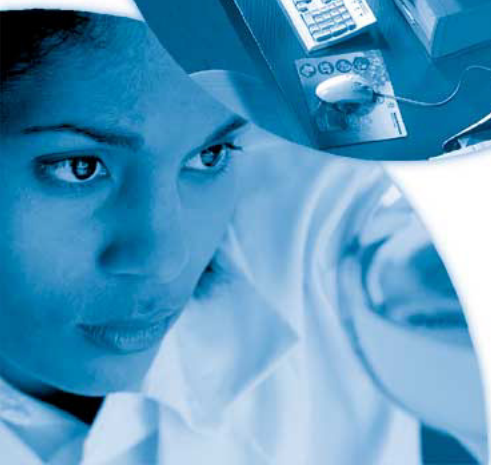




# **Agilent ChemStation for UV-visible Spectroscopy**



## **Understanding Your UV-visible Spectroscopy System**



**Agilent Technologies**

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## In This Guide...

This manual describes the data processing operations of the Agilent 8453 spectrophotometer and the Agilent ChemStation for UV-visible spectroscopy. It describes the processes and transformations that the spectrophotometric data undergo between the time that they are acquired in the spectrophotometer and their output on the Agilent ChemStation display or printer. The manual is designed to enable you to follow good laboratory practice (GLP) guidelines; using the information in the manual, you will be able to understand the data processing calculations from beginning to end and perform the data evaluation manually.

### **1 Overview of Data Processing**

This chapter gives an overall summary of how data are acquired and processed in the spectrophotometer, transferred to, and then processed and reported by the Agilent ChemStation.

### **2 Agilent ChemStation Registers and Views**

This chapter explains the concepts of registers and views, which are the bases of data storage and display in the Agilent ChemStation.

### **3 Tasks**

This chapter describes the parameters and operation of the four Agilent ChemStation tasks: Fixed Wavelengths, Spectrum/Peaks, Ratio/Equation, and Quantification.

### **4 Spectral Processing and Data Transformation**

This chapter contains details of the how math functions are used to process raw spectral data, and how wavelength data are extracted from processed data for evaluation

### **5 Evaluation**

This chapter explains the Agilent ChemStation evaluation procedures.

## **6 Reports**

This chapter contains descriptions of format and contents of the reports that are available with the general purpose UV-visible software for the Agilent ChemStation

## **7 Interactive Math Functions**

This chapter contains full explanations of the math functions, including their operation at limiting conditions

## **8 Configuration and Methods**

This chapter explains details of configuration and describes the software structure and method operation

## **9 Verification**

This chapter describes the process of system verification and describes each of the verification tests in detail. Verification is the process of evaluating your spectrophotometer to ensure that it complies with documented specifications.

# Contents

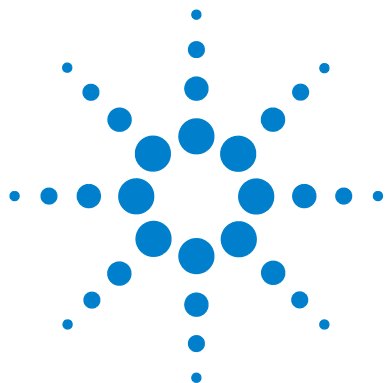
<b>1</b>	<b>Overview of Data Processing</b>	<b>9</b>
	Data Processing in the Agilent 8453 Spectrophotometer	10
	Agilent 8453	11
	Dark Current Correction	12
	Stray Light Correction	12
	Variance	12
	Reference Spectrum	12
	Absorbance Spectra	13
	Wavelength Calibration	14
	Invalid Data	14
	Data Flow in the Agilent ChemStation	15
	Data Flow for Samples	15
	Data Flow for Standards	16
<b>2</b>	<b>Agilent ChemStation Registers and Views</b>	<b>19</b>
	Registers	20
	Structure and Contents of Registers	21
	Data Structure of Spectra	23
	Views	24
	Relationship Between Views and Registers	24
<b>3</b>	<b>Tasks</b>	<b>25</b>
	Fixed Wavelength Task	26
	Spectrum/Peak	27
	Ratio/Equation	28

	Quantification	30
<b>4</b>	<b>Spectral Processing and Data Transformation</b>	<b>33</b>
	Spectral Processing	34
	Absorbance	34
	Transmittance	34
	Derivative	34
	Data Transformation	35
	Use Wavelengths	35
	Background Correction	35
<b>5</b>	<b>Evaluation</b>	<b>39</b>
	Evaluation using an Equation	40
	Quantification	41
	Beer-Lambert Law	41
	Calibration	42
	Calibration Results	48
	Quantification of Unknown Samples	50
<b>6</b>	<b>Reports</b>	<b>51</b>
	Method Report	53
	Results Report	55
	Automation Reports	56
<b>7</b>	<b>Interactive Math Functions</b>	<b>57</b>
	Unitary Operations	58
	Absorbance	58
	Transmittance	59
	Derivative	60
	Scalar Add	63
	Scalar Multiply	63

Binary Operations	64
Add	64
Subtract	66
<b>8 Configuration and Methods</b>	<b>69</b>
System Configuration	70
Configuring the Hardware	70
The Configuration File	72
Methods	73
The Structure of Methods	73
Method Files	74
On Using a Method	75
The ChemStation.ini File	77
The Directory Structure	78
File Formats	81
<b>9 Verification</b>	<b>83</b>
Configuration of Verification	84
Verification Tests	85
Wavelength Accuracy	85
Photometric Accuracy	88
Stray Light	90
Resolution	90
Noise	91
Baseline Flatness	92
Stability	93
Spectrophotometer Selftests	94
Flow Test	95
<b>Index</b>	<b>97</b>







# 1

## Overview of Data Processing

Data Processing in the Agilent 8453 Spectrophotometer 10

Data Flow in the Agilent ChemStation 15

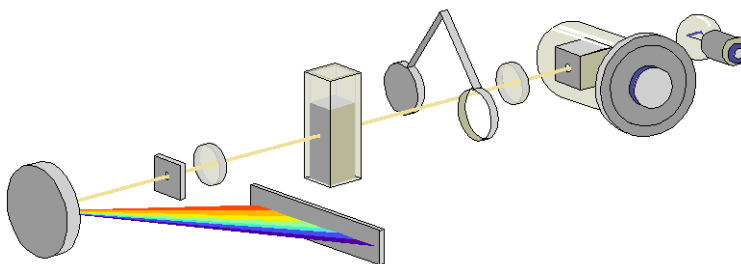


## Data Processing in the Agilent 8453 Spectrophotometer

The following sections give an outline of how the Agilent 8453 spectrophotometer evaluates and processes spectra. All of these processes are implemented in firmware within the instrument. Since *raw* data is generally considered to be the actual values delivered by the measurement device to the controller (that is, the absorbance values), only an overview of the internal data processing is given here. Details of the algorithms are not provided.

## Agilent 8453

The optical system of the Agilent 8453 is shown in [Figure 1](#). It uses two light sources, a deuterium and a tungsten lamp. The shutter consists of two parts; one serves simply as an optical on/off switch, the second is a filter used to reduce stray light in the UV range. The 1024-element diode-array is a series of silicon photodiodes which are sensitive to light. Each photodiode is connected to a capacitor which is recharged at a constant interval by the control electronics. When light falls on a photodiode its resistance changes proportional to the incident light and the capacitor is discharged. The amount of electricity required to recharge the capacitor at each recharge cycle is a measure of the light intensity.



**Figure 1** Optical Path of the Agilent 8453 Spectrophotometer

The readout circuitry of the diode-array produces an analog signal which is fed to an analog-to-digital converter for conversion into the digital domain. The output from the A/D converter is a digital intensity spectrum expressed in counts.

## Dark Current Correction

When the shutter is closed and no light falls on the array there is still a low-level signal due to leakage from the capacitor. This is called the “dark current”. The dark current signal is continually measured and stored within the electronics. It is automatically subtracted from the signal obtained when the shutter is opened.

## Stray Light Correction

In a standard measurement sequence, reference or sample intensity spectra are measured without and then with the stray light filter in the light beam. Without the filter the intensity spectrum over the whole wavelength range from 190-1100 nm is measured. The stray light filter is a blocking filter with 50% blocking at 420 nm. With this filter in place any light measured below 400 nm is stray light. This stray light intensity is then subtracted from the first spectrum to give a stray light corrected spectrum.

## Variance

The instrument’s read-out rate of the diode array is 100 msec. By means of the integration time, data can be acquired using multiples of the readout time. If an integration time greater than 100 msec is applied, multiple spectra, dependent upon the selected integration time, are acquired. An average spectrum is calculated and, if requested, variance data for each data are calculated in addition.

## Reference Spectrum

The Agilent 8453 is a single beam spectrophotometer. To generate a sample spectrum two steps are required. First a “reference” intensity spectrum,  $I_0$ , is measured. This is usually measured on the cuvette with solvent. This reference intensity spectrum is stored internally with the Agilent 8453.

## Absorbance Spectra

For a sample, the intensity spectrum is measured and the absorbance spectrum is calculated (no stray light correction) using:

$$A = -\log((I_s - I_{sd}) / (I_0 - I_{0d}))$$

where

$I_0$  is the reference intensity measured with the blank

$I_{0d}$  is the dark current measured immediately before the reference

$I_s$  is the intensity measured with the sample

$I_{sd}$  is the dark current measured immediately before the sample.

This absorbance spectrum together with the variance of each data point (if requested) is then transmitted to the controller.

When stray light correction is activated,  $I_s$  and  $I_0$  are also corrected in the range 190 – 400 nm by subtracting the measured stray light:

$$A = -\log((I_s - I_{sd} - I_{s(\text{stray})}) / (I_0 - I_{0d} - I_{0(\text{stray})}))$$

where

$I_{0(\text{stray})}$  is the stray light intensity measured with the blank

$I_{s(\text{stray})}$  is the stray light intensity measured with the sample

## Wavelength Calibration

The Agilent 8453 has a nominal sampling interval of 1 diode every 0.9 nm. Each spectrograph is calibrated in the factory using a series of emission lines from deuterium, zinc, argon and mercury lamps to obtain a calibration curve that relates each diode to a particular wavelength. The calibration parameters of this curve are stored within the ROM memory of each spectrograph. On site, this calibration can be checked by using the two emission lines from the deuterium lamp. With the aid of the calibration parameters, the firmware of the spectrophotometer determines absorbance values at 1 nm intervals and these values are then sent to the controller.

## Invalid Data

The Agilent 8453 will *invalidate* a measured spectrum under certain circumstances. This means that the measured spectrum is considered to be so unreliable that it is not usable. In the spectrum sent to the controller the absorbance values at wavelength which are invalidated are set to a special value which is recognized by the controller software and these values are not displayed. Invalid data are produced when the sample is much more transparent than the reference data of the previously acquired blank. This causes an A/D converter overflow.

## Data Flow in the Agilent ChemStation

The data flow in the Agilent ChemStation software can be considered as two separate processes for samples and standards. The data flows are linked by the calibration data that is produced during the processing of standards and used in the evaluation of samples.

### Data Flow for Samples

Figure 2 shows the flow of sample data through the Agilent ChemStation registers from the transfer of the sample absorbance values and statistics from the spectrophotometer to the Agilent ChemStation to the production of a printed report. For qualitative evaluations with no quantification, the calibration data is not included in the evaluation.

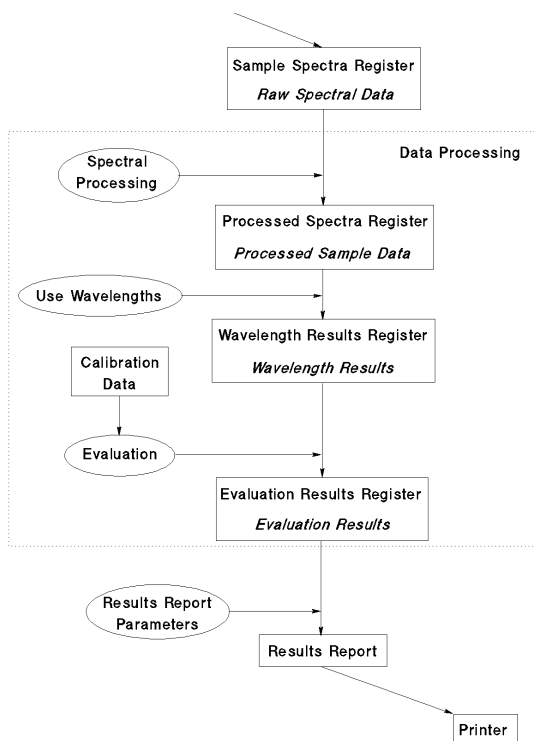
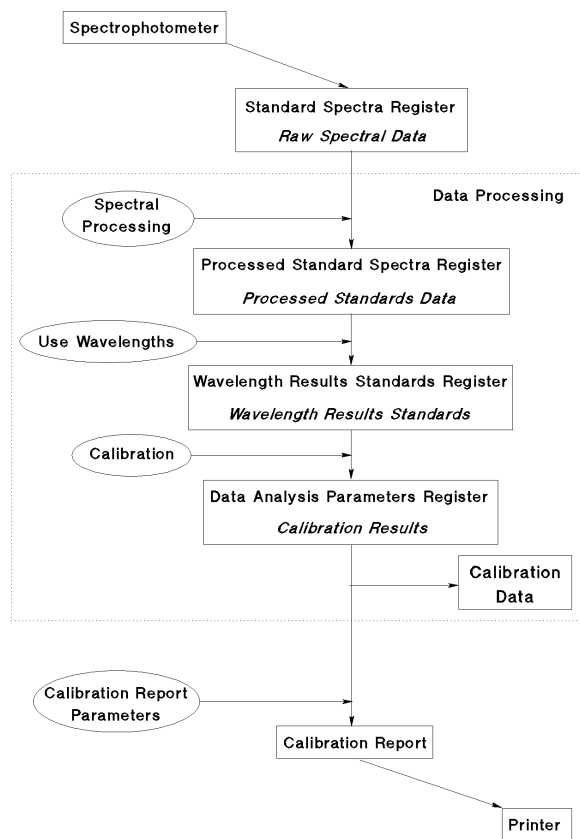


Figure 2 Data Flow for Samples

## Data Flow for Standards

Data flow during the calibration process, which is concerned only with standard samples, is shown in Figure 3.



**Figure 3** Data Flow for Standards



The calibration coefficients that are calculated during the calibration process are stored with the data analysis parameters in the Data Analysis Parameters register as part of the current method.

Once a calibration has been performed, and the calibration coefficients have been added to the Data Analysis Parameters register, the quantitative evaluation procedure uses the stored calibration data to perform a quantitative analysis on all subsequent samples that are measured using the current method. It is important to note that no data are destroyed during any of the data processing operations.

## **1 Overview of Data Processing**

### **Data Flow in the Agilent ChemStation**



## 2 Agilent ChemStation Registers and Views

Registers 20

Views 24



## Registers

A register is an area of computer memory where data are stored. The General Scanning software sets up several registers for different types of data; the most important registers are shown in [Table 1](#).

**Table 1** Agilent ChemStation Registers and Their Contents

Register	Contents
Configuration	System configuration data (see <a href="#">Chapter 8, “Configuration and Methods”</a> )
Sample System Parameters	Sampling system parameters to be used for measurements
Spectrophotometer Parameters	Spectrophotometer measurement parameter
Blank Spectrum	Last acquired blank spectrum
Raw Data (Sample Spectra)	Unprocessed data from sample measurements (usually absorbance data)
Raw Data (Standard Spectra)	Unprocessed data from standard sample measurements (usually absorbance data)
Math Result	Results of interactive math processing
Method Description	Definition of the method (see <a href="#">Chapter 8, “Configuration and Methods”</a> )
Data Analysis Parameters	Definitions and parameters of all data processing steps
Processed Sample Spectra	Spectral data from samples after spectral processing
Processed Standard Spectra	Spectral data from standards after spectral processing

**Table 1** Agilent ChemStation Registers and Their Contents (continued)

Register	Contents
Wavelength Results	Function results from the specified wavelengths of the sample spectra
Wavelength Results Standards	Function results from the specified wavelengths of the standard spectra
Evaluation Results	Evaluation or analysis results
Evaluation Results Standards	Evaluation results that are used for calibration diagnostics

The registers which are specific to the standard samples and calibration data are used in the Quantification task only. During Quantification, the Data Analysis Parameters register includes the calibration coefficients generated during calibration process.

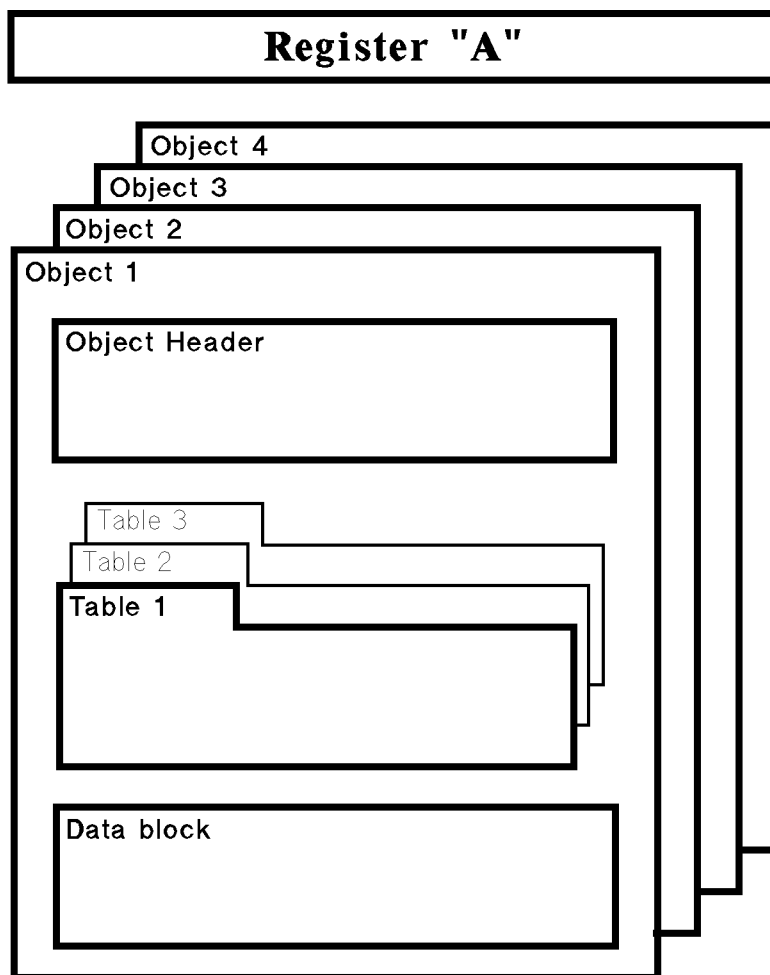
In addition, registers are set up for instrument parameters, method and automation parameters and analysis results. Temporary registers are also set up during data processing and during the execution of tasks.

## Structure and Contents of Registers

All registers have the same basic structure, which is similar to a database or card-index system. The fundamental unit of the register is the **object**, which is equivalent to a record in a database or a single card in a card index system. For example, a measured spectrum is an object in the raw data register. Each object has three parts:

- the **object header**, which contains static information about the object,
- a group of **tables**, which contain dynamic information about the object,
- the **data block**, which contains the object's data.

A graphical representation of the structure of a register is shown in [Figure 4](#) on page 22.



**Figure 4** Register Structure

## Data Structure of Spectra

The data structure of spectra is the same in the Samples register and the Math Result register:

- Header block, containing some or all of the following information:

Information about the sample:

- the sample name,
- solvent information (if available),
- any available comment,
- the operator name,
- the data type (absorbance).

Information about the instrument on which the sample was run:

- the identification of the type and firmware revision number,
- the instrument serial number (Agilent 8453).

Information about the acquisition:

- the date and time of acquisition,
- the integration time,
- the resolution,
- cell path length and units,
- cell temperature (if available).
- The Analytes Table, containing the information about the analytes. If no analyte information is available, this table is empty.
- The Data Block, containing the spectral information in a matrix of three rows:
  - the wavelength in ascending order,
  - the absorbance at that wavelength,
  - the standard deviation of the measurement, calculated from the variance data transferred from the spectrophotometer.

## Views

Views are perspectives on the contents of registers. Each view displays the contents of the relevant registers in one or more windows; each window of the view displays a portion of the registers' contents.

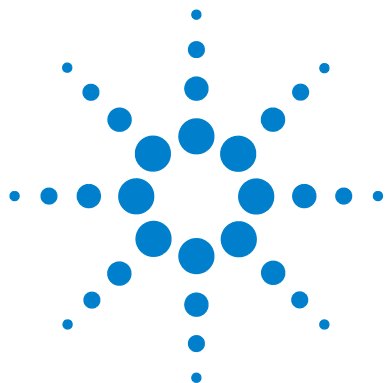
### Relationship Between Views and Registers

The Samples view and Math view display the contents of the Processed Samples register and Math Result register respectively:

- The Sample Spectra window and Math Result window are graphical representations of the Data Blocks from the respective registers.
- The Sample/Result table of the Samples view contains selected information from the Header block, together with the evaluation results. The Samples Table, accessible from the Sample/Result table, contains additional information from the Header block.

The Standards view displays the contents of the Processed Standard Spectra register.





### 3 Tasks

Fixed Wavelength Task	26
Spectrum/Peak	27
Ratio/Equation	28
Quantification	30



# Fixed Wavelength Task

For details of the calculations used in this task, see [Chapter 5](#), “Evaluation”.

The Fixed Wavelength task allows the calculation of results from up to six wavelengths with or without background correction. The Fixed Wavelength parameters are shown in [Table 2](#):

**Table 2**    Parameters for the Fixed Wavelength Task

Parameter	Data Flow	Range of Values
Use Wavelength(s)	Sets the Used Wavelengths (see <a href="#">“Use Wavelengths”</a> on page 35) to the selected values.	Up to six single wavelengths
Background Correction	Sets the Background Correction (see <a href="#">“Background Correction”</a> on page 35) to the selected type.	none single reference wavelength subtract average over a range three-point drop line
Data Type	Sets the Spectral Processing (see <a href="#">“Spectral Processing”</a> on page 34) to the selected type.	Transmittance Absorbance Derivative 1 Derivative 2 Derivative 3 Derivative 4
Display Spectrum	Sets the upper and lower wavelength limits for spectral display.	Instrument Settings

## Spectrum/Peak

For details of the calculations used in this task, see [Chapter 5](#), “Evaluation”.

The Spectrum/Peaks task determines the maxima and minima of the data points (y-values) in the defined wavelength range of the spectrum. The last acquired spectrum is displayed annotated with the specified number of peaks and valleys, and the Sample Result table shows the wavelengths and absorbance values of the peaks and valleys. The All Peaks/Valleys button displays a list of the wavelengths and absorbencies of all peaks and valleys.

The original spectrum is first derivatized (see “[Derivative](#)” on page 60) using a filter length of 5 and a polynomial degree of 3. The derivatized y-values are examined for transitions (change of sign); each transitional y-value is compared with its neighboring values, and if the neighboring values are more extreme, the transitional y-value is compared with the previous transitional y-value. If the difference of both values is greater than or equal to the sensitivity threshold, then the previous transitional point is stored as an extremum; if the difference is less than the sensitivity threshold, then neither point is stored.

The Spectrum/Peaks parameters are shown in [Table 3](#):

**Table 3** Parameters for the Peak / Valley Find Task

Parameter	Data Flow	Range of Values
Data Type	Sets the Spectral Processing (see “ <a href="#">Spectral Processing</a> ” on page 34) to the selected type.	Transmittance Absorbance Derivative 1 Derivative 2 Derivative 3 Derivative 4
Display Spectrum	Sets the upper and lower wavelength limits for spectral display	Instrument Settings
Number of Peaks	Sets the number of peaks reported.	0 to 19
Number of Valleys	Sets the number of valleys reported.	0 to 19

# Ratio/Equation

For details of the calculations used in this task, see [Chapter 5](#), “Evaluation”.

The Ratio/Equation task calculates a result based upon a specified equation. The equation can contain absorbencies from up to six wavelengths plus sample weight and volume information. The following mathematical operators are available for use in an equation:

+	adds
-	subtracts
/	divides
*	multiplies
<b>ABS(exp)</b>	returns the absolute value of the expression
<b>Ceil(exp)</b>	rounds the expression up to the nearest integer
<b>EXP(exp)</b>	returns $e^{(\text{exp})}$
<b>FLOOR(exp)</b>	rounds the expression down to the nearest integer
<b>LN(exp)</b>	returns the natural logarithm (base e) of the expression
<b>LOG(exp)</b>	returns the logarithm (base 10) of the expression
<b>SQR(exp)</b>	returns the square of the expression
<b>SQRT(exp)</b>	returns the square root of the expression

The results of the equation are corrected for path length and dilution factor automatically.

The parameters for the Ratio/Equation task are shown in [Table 4](#):

**Table 4**    Parameters for the Ratio/Equation Task

Parameter	Data Flow	Range of Values
Use Wavelength(s)	Sets the Used Wavelengths (see “Use Wavelengths” on page 35) to the selected values.	Up to six single wavelengths
Data Type	Sets the Spectral Processing (see “Spectral Processing” on page 34) to the selected type.	Transmittance Absorbance Derivative 1 Derivative 2 Derivative 3 Derivative 4
Equation Name	Sets the equation name.	Alphanumeric text
Equation	Sets the equation parameters.	Alphanumeric text
Unit	Sets the units for the result.	Alphanumeric text
Use sample weight and volume	Switches on the Weight and Volume entry fields in the Sample Information dialog box.	Checked (yes) or unchecked (no)
Prompt for sample information	Switches on the display of the Sample Information dialog box after sample measurement.	Checked (yes) or unchecked (no)
Display Spectrum	Sets the upper and lower wavelength limits for spectral display	Instrument Settings

# Quantification

For details of the calculations used in this task, see [Chapter 5](#), “Evaluation”.

The Quantification task calculates calibration coefficients from the measured data of a set of standards, then uses the calibration coefficients to determine the concentration of unknown samples. The equations used in the calculation of the calibration coefficients and the concentrations of unknown samples are given in [Chapter 5](#), “Evaluation”. The parameters for the Quantification task are shown in [Table 5](#):

**Table 5**    Parameters for the Quantification Task

Parameter	Data Flow	Range of Values
Use Wavelength	Sets the Used Wavelengths (see <a href="#">“Data Transformation”</a> on page 35) to the selected values.	Single wavelength value
Background Correction	Sets the Background Correction (see <a href="#">“Background Correction”</a> on page 35) to the selected type.	none single reference wavelength subtract average over a range three-point drop line
Analyte name	Sets the analyte name.	Alphanumeric text
Calibration Curve Type	Sets the calibration curve type (see <a href="#">“Calibration Curve Types”</a> on page 42.)	linear (Beer’s law) linear with offset quadratic quadratic with offset
Concentration unit	Sets the units of concentration; when the Concentration option is chosen, switches on the Concentration entry field in the Sample Information dialog box.	alphanumeric text
Weight & Volume unit	Sets the units of weight and volume; when the Weight & Volume option is chosen, switches on the Weight and Volume entry fields in the Sample Information dialog box.	alphanumeric text

**Table 5** Parameters for the Quantification Task (continued)

Parameter	Data Flow	Range of Values
Prompt for standard information	Switches on the display of the Standard Information dialog box after sample measurement.	Checked (yes) or unchecked (no)
Prompt for sample information	Switches on the display of the Sample Information dialog box after sample measurement.	Checked (yes) or unchecked (no)
Data Type	Sets the Spectral Processing (see “Spectral Processing” on page 34) to the selected type.	Transmittance Absorbance Derivative 1 Derivative 2 Derivative 3 Derivative 4
Display Spectrum	Sets the upper and lower wavelength limits for spectral display	Instrument Settings

### 3 Tasks

#### Quantification





## 4 Spectral Processing and Data Transformation

Spectral Processing 34

Data Transformation 35



## Spectral Processing

### Absorbance

Absorbance is the default data type of spectral storage in the UV-visible ChemStation.

Absorbance spectra are calculated using the Absorbance function; for a complete description of the mathematical processes involved in calculating absorbance spectra, see [“Absorbance”](#) on page 58.

### Transmittance

Transmittance spectra are calculated using the Transmittance function; for a complete description of the mathematical processes involved in calculating transmittance spectra, see [“Transmittance”](#) on page 59.

### Derivative

First, second, third and fourth order derivative spectra can be calculated. The Derivative functions calculate the derivative of the data points (y-values) in the spectrum to the specified derivative order using a Savitsky-Golay algorithm with a filter length of 5 and a polynomial degree of 3. For a complete description of the Derivative function, see [“Derivative”](#) on page 60.

## Data Transformation

### Use Wavelengths

The Use Wavelengths function selects a sub-set of data from the full spectrum. The sub-set may be the processed spectral intensity value at a single wavelength, as in the Quantification task, or the processed spectral intensity values at up to six wavelengths as in the Fixed Wavelengths and Ratio/Equation tasks. The extracted value(s) may then be subjected to further modification by background correction to produce the final result.

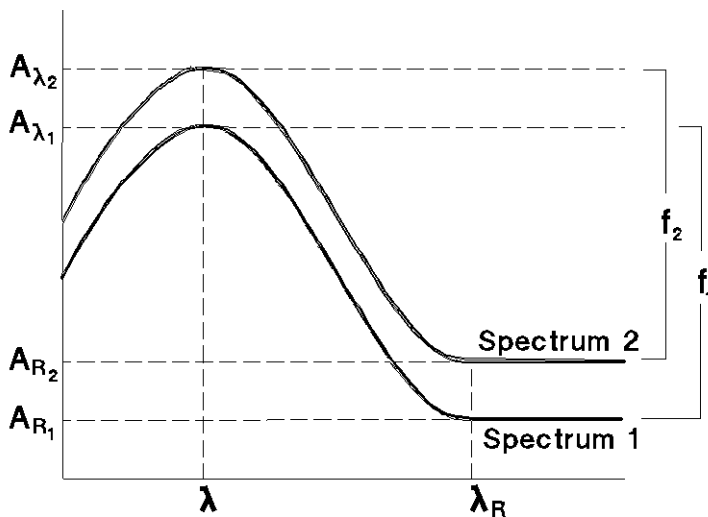
### Background Correction

Background correction subtracts a calculated “background” value from the extracted spectral intensity value(s). There are three methods of calculating the background values:

- single reference wavelength
- subtract average over a range
- three-point drop line, used when two wavelengths are set

#### Single Reference Wavelength

The single reference wavelength method subtracts the spectral intensity value at a specified wavelength, as in [Figure 5](#) on page 36. The reference wavelength is usually selected at a point on the baseline beyond the sample absorbance.



**Figure 5** Background Correction to a Single Reference Wavelength

Subtraction is carried out using Equation 1:

$$f_{\lambda} = A_{\lambda} - A_{R_{\lambda}} \quad (1)$$

where

$f_{\lambda}$  is the function result at wavelength  $\lambda$

$A_{\lambda}$  is the absorbance at wavelength  $\lambda$

$A_{R_{\lambda}}$  is the absorbance at reference wavelength  $\lambda$

The variances (if available) are treated according to Equation 2:

$$\text{var}(f_{\lambda}) = \text{var}(A_{\lambda}) + \text{var}(A_{R_{\lambda}}) \quad (2)$$

where

$\text{var}(f_{\lambda})$  is the variance of the function result at wavelength  $\lambda$

$\text{var}(A_{\lambda})$  is the variance of the absorbance at wavelength  $\lambda$

$\text{var}(A_{R_{\lambda}})$  is the variance of the absorbance at reference wavelength  $\lambda$

### Subtract Average Over Range

The subtract average over range method uses the same calculation as for a single reference wavelength (see “Single Reference Wavelength” on page 35), but replaces the spectral intensity value at the single wavelength with the average intensity value over a specified wavelength range.

$$f_{\lambda} = A_{\lambda} - \left( \frac{A_{R_1} + A_{R_2} + A_{R_3} + \dots + A_{R_n}}{n} \right)$$

where the terms are the same as for a single reference wavelength (see “Background Correction” on page 35).

### Three-Point Drop Line

For a three-point drop-line background correction, the spectral intensity and variance values from two reference wavelengths are taken, giving  $A_{R_1}$ ,  $A_{R_2}$ ,  $\text{var}(A_{R_1})$  and  $\text{var}(A_{R_2})$ . In this case, the reference wavelengths define a straight line (as in Figure 6 on page 38) which is used to calculate  $A_{R_{\lambda}}$  and  $\text{var}(A_{R_{\lambda}})$  using Equation 3 and Equation 4.

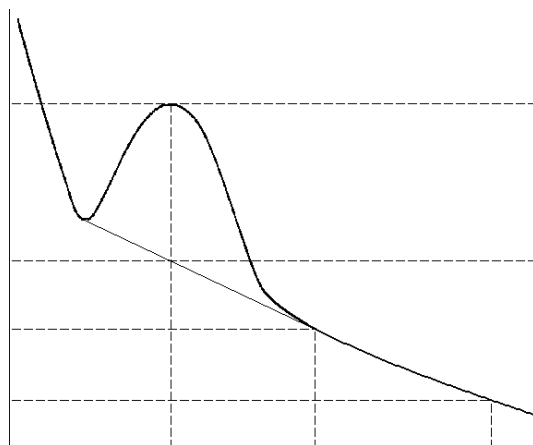
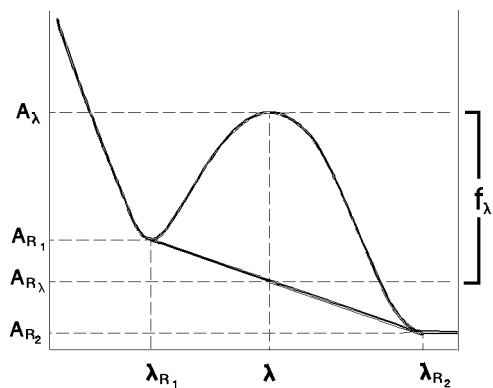
$$A_{R_{\lambda}} = \frac{1}{\lambda_{R_2} - \lambda_{R_1}} \{ (\lambda_{R_2} - \lambda) A_{R_1} + (\lambda - \lambda_{R_1}) A_{R_2} \} \quad (3)$$

$$\text{var}(A_{R_{\lambda}}) = \frac{1}{(\lambda_{R_2} - \lambda_{R_1})^2} \left\{ (\lambda_{R_2} - \lambda)^2 \text{var}(A_{R_1}) + (\lambda - \lambda_{R_1})^2 \text{var}(A_{R_2}) \right\} \quad (4)$$

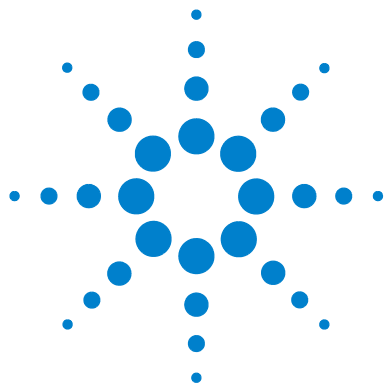
where the terms are the same as for a single reference wavelength (see “Background Correction” on page 35). In Figure 6 on page 38, the upper trace shows the spectrum before background correction, with the three-point drop line superimposed. The lower trace shows the spectrum after background correction.

## 4 Spectral Processing and Data Transformation

### Data Transformation



**Figure 6** Three-point Drop Line



## 5 Evaluation

Evaluation using an Equation	40
Quantification	41

This chapter describes the use of equations, and introduces quantification and explains the concepts that are used in the Quantification task of the software. It also describes the mathematical and statistical calculations that are used to produce a calibration curve for single component analysis and how the quantitative results are calculated using the calibration data.



## Evaluation using an Equation

When an equation evaluation is specified, the analysis results are the results of the equation specified in the Equation Parameter dialog box. In the definition of the equation, you can use any result generated by the Use Wavelength(s) and stored in the Wavelength Results register and any of the other predefined variables: Dilution factor, Weight and Volume.

By default, the results are normalized to a 1 cm path length by dividing the function result by the value of the Path Length parameter in the Sample Spectra table:

$$f_{\text{corr}} = \frac{f}{l} \quad (5)$$

where

$f_{\text{corr}}$  is the function result after path length correction

$f$  is the uncorrected function result

$l$  is the path length



## Quantification

The Quantification task of the Agilent ChemStation software includes facilities for:

- measurement of calibration standards,
- calibration of a single analyte using the calibration standards,
- measurement of unknown samples, and
- quantification of the analyte in the unknown samples.

### Beer-Lambert Law

The Beer-Lambert law states that the absorbance of a solute is directly proportional to its concentration:

$$A = Ecd \quad (6)$$

In [Equation 6](#):

$A$  is absorbance

$E$  is molar absorptivity or molar extinction coefficient ( $\text{l.mol}^{-1}.\text{cm}^{-1}$ )

$c$  is analyte concentration ( $\text{mol.l}^{-1}$ )

$d$  is cell path length (cm)

To calculate the concentration of an unknown compound, the above equation can be solved for a given function result,  $f$ :

$$c = \frac{f}{Ed} \quad (7)$$

The reciprocal of the product of molar extinction coefficient and cell path length is often called the calibration coefficient,  $k$ .

$$c = kf \quad (8)$$

## Calibration

Calibration is the correlation of the **function result** with known concentrations of sample. The basic assumption is that the variance in the measured data is less than the variance in the standard concentrations. As a result of this correlation a **calibration curve** can be fitted to the data points and **calibration coefficients** can be calculated. The concentrations of unknown samples can then be calculated from the calibration coefficients and the function result of the samples.

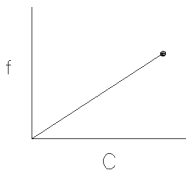
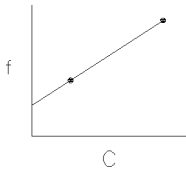
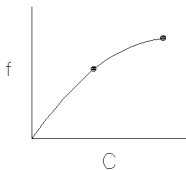
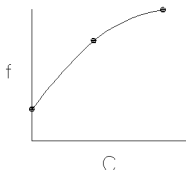
### Calibration Curve Types

Real data may deviate slightly from the ideal linear relationship described in “[Beer-Lambert Law](#)” on page 41. The relationship between the function result and concentration may be described more accurately by adding an offset (a non-zero intercept) or a quadratic term (or both) to the equation.

The ChemStation provides four different calibration curve types, shown in [Table 6](#). These calibration curve graphs are shown in the more traditional way with the concentration on the x-axes and the function results on the y-axes.

The Agilent ChemStation provides four different calibration curve types, shown in [Table 6](#).

**Table 6** Calibration Curve Types for Single Component Analysis

Curve Type	Curve	Equation
I Linear without zero offset		$c = k_1 f$
II Linear with zero offset		$c = k_0 + k_1 f$
III Quadratic without zero offset		$c = k_1 f + k_2 f^2$
IV Quadratic with zero offset		$c = k_0 + k_1 f + k_2 f^2$

$c$  is the concentration

$f$  is the function result

$k_0$ ,  $k_1$ ,  $k_2$  are calibration coefficients

### Number of Standards

There is no fixed limit to the number of calibration standards that can be incorporated into a calibration; the more points that can be placed on the curve, the more accurately the curve can be characterized. However, each of the calibration curve types requires a minimum number of standards of

different concentrations (see [Table 7](#)).

**Table 7**    Minimum Number of Standards for Calibration Curves

Calibration Curve Type	Minimum Number of Standards
Linear, no zero offset (Beer's law)	1
Linear with zero offset	2
Quadratic, no zero offset	2
Quadratic with zero offset	3

### Calibration Standards

If the absorbance of the analyte at the wavelength(s) you select strictly obeys Beer's Law, then one standard is sufficient to characterize the calibration curve (linear without zero offset). However, the use of two standards at different concentrations will confirm adherence to Beer's Law, or show up any irregularities. Two standards are necessary to characterize a linear calibration curve with zero offset. Addition of a third standard at a different concentration is sufficient to identify and characterize a non-linear calibration curve.

## Calibration Curve Fits

The mathematical problem is to find the calibration coefficients in a given curve type which will allow the best determination of a future unknown sample.

The least squares method uses the analytical function data from Use Wavelengths of all standards to determine the calibration coefficients of the chosen calibration curve type by a least squares calculation.

If each  $i$ th data set  $(f_i, c_i)$  of the  $n$  standard data sets is expected to obey a function in the  $p$  coefficients,  $k_j$ , although the real (measured) values may cluster around the function because of statistical errors,  $\varepsilon_i$ , then the general equation is:

$$c_i = k_0 + k_1 f_i + k_2 f_i^2 + \varepsilon_i \quad (9)$$

where

$i$  is 1, 2, 3, ...  $n$  (the total number of standards)

The calibration coefficients,  $k_j$ , can be estimated using the least squares method, that is minimizing the sum of the squares of the errors,  $\varepsilon_i$  (the differences between the measured value and the calibration curve).

$$\sum_{i=1}^n (c_{actual_i} - c_{calculated_i})^2 = \sum_{i=1}^n \varepsilon_i^2 = \text{minimum} \quad (10)$$

In matrix notation:

$$C = Fk + \varepsilon \quad (11)$$

where

$C$  is  $n$ -concentration column vector

$F$  is  $n \times p$  function result data matrix

$k$  is  $p$ -calibration coefficient column vector

$\varepsilon$  is  $n$ -error column vector

The elements used in the calibration matrix  $F$  and the coefficient vector  $k$  are given in Table 8 on page 46 with dimension  $p$  of the coefficient vector.

**Table 8** Elements used in calibration matrix  $F$

Curve Type	p	$F_{(i)\text{th row}}$			$k$		
I	1	$f_i$	—	—	$k_1$	—	—
II	2	1	$f_i$	—	$k_0$	$k_1$	—
III	2	$f_i$	$f_i^2$	—	$k_1$	$k_2$	—
IV	3	1	$f_i$	$f_i^2$	$k_0$	$k_1$	$k_2$

### Example

Using curve type III, where  $p = 2$ , for 5 standards,  $n = 5$ :

$$c_1 = k_1 f_1 + k_2 f_1^2 + \varepsilon_1$$

through to

$$c_5 = k_1 f_5 + k_2 f_5^2 + \varepsilon_5$$

That is:

$$\begin{bmatrix} c_i \\ \vdots \\ c_5 \end{bmatrix} = \begin{bmatrix} f_1 & f_1^2 \\ \vdots & \vdots \\ f_5 & f_5^2 \end{bmatrix} \begin{bmatrix} k_1 \\ k_2 \end{bmatrix} + \begin{bmatrix} \varepsilon_i \\ \vdots \\ \varepsilon_5 \end{bmatrix}$$

or, in matrix notation:

$$C = Fk + \varepsilon$$

By defining  $F$  and  $k$  for each of the calibration curve types, the coefficients are given by the general equation:

$$k = (F^T F)^{-1} F^T C \quad (12)$$

where

$F^T$  denotes the transpose of  $F$

**Example Continued:**

$$\begin{bmatrix} k_1 \\ k_2 \end{bmatrix} = \left( \begin{bmatrix} f_1 & \dots & f_5 \\ f_1^2 & \dots & f_5^2 \end{bmatrix} \begin{bmatrix} f_1 & f_1^2 \\ \dots & \dots \\ f_5 & f_5^2 \end{bmatrix} \right)^{-1} \left( \begin{bmatrix} f_1 & \dots & f_5 \\ f_1^2 & \dots & f_5^2 \end{bmatrix} \begin{bmatrix} c_1 \\ \dots \\ c_5 \end{bmatrix} \right)$$

## Calibration Results

This section contains the equations used in the calculations of the results given in the Calibration Table and the Calibration Results Summary.

### Residual

$$e_i = C_{actual_i} - C_{calculated_i} \quad (13)$$

### %Error

$$d_i = \frac{e_i}{C_{calculated_i}} \times 100 \quad (14)$$

where

$e_i$  is the residual of the  $i^{\text{th}}$  standard (see “Residual” on page 48)

### Std.Dev of Calibration

$$s = \sqrt{\frac{1}{(n-p)} \sum_{i=1}^n e_i^2} \quad (15)$$

where

$e_i$  is the residual of the  $i^{\text{th}}$  standard

$n$  is the number of standards

$p$  is the number of coefficients in the equation of the calibration curve



### Std.Dev of Coefficient k

$$s_{k_j} = s \sqrt{(F^T F)^{-1}_{jj}} \quad (16)$$

where

$(F^T F)^{-1}_{jj}$  is the  $j^{\text{th}}$  diagonal element of  $(F^T F)^{-1}$

$s$  is the standard deviation of calibration (see “Std.Dev of Calibration” on page 48)

### Correl. Coeff ( $R^2$ )

$$R^2 = \frac{\sum_{i=1}^n (C_{\text{calculated}_i} - \bar{C})^2}{\sum_{i=1}^n (C_{\text{actual}_i} - \bar{C})^2} \quad (17)$$

In the case of curve types II and IV,

$$\bar{C} = \frac{1}{n} \sum_{i=1}^n C_i \quad (18)$$

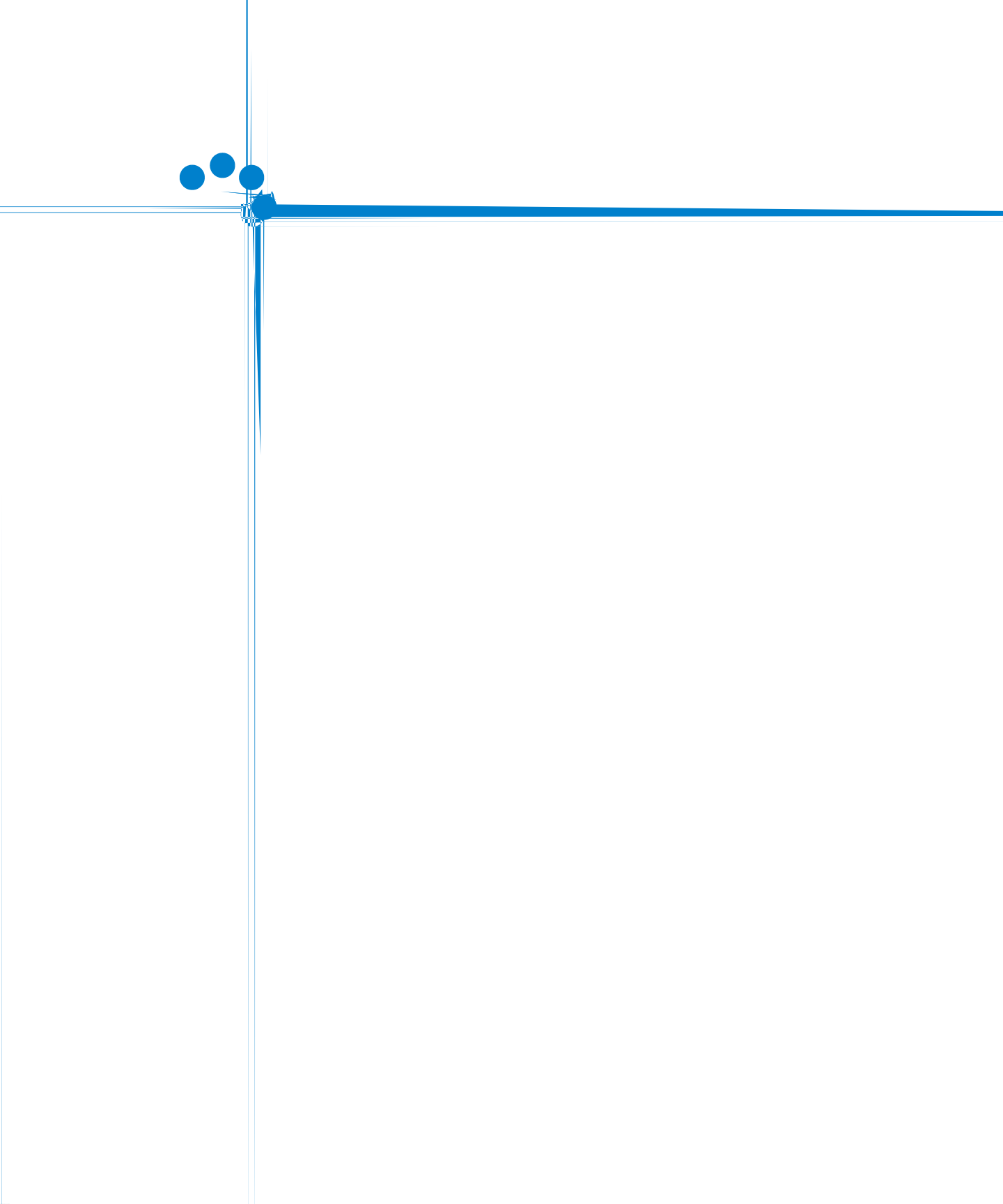
In the case of curve types I and III,  $\bar{C}$  is set to zero.

## Quantification of Unknown Samples

When the standards have been measured, and the calibration coefficients have been determined, the unknown concentration of a measured sample can be calculated simply by calculating  $C_{unk}$  in the equation of the calibration curve using the function result data,  $f_{unk}$  of the unknown sample:

$$C_{unk} = k_0 + k_1 f_{unk} + k_2 f_{unk}^2 \quad (19)$$

where  $k_0$ ,  $k_1$  or  $k_2$  may be zero depending on the calibration curve type (see [Table 6](#) on page 43).



The appearance of the report is affected by two sets of parameters:

- The report configuration parameters control the margins, and indents for textual data. The annotation limit, which is the maximum number of spectra that are annotated, is also controlled by the report configuration parameters. If a spectrum plot contains less spectra than the annotation limit, all spectra are annotated. If the spectrum plot contains more spectra than the annotation limit, none of the spectra are annotated.
- The printer setup parameters control the target printer and the paper size and orientation.

The title of the report contains the task name together with the date and time of generation.

## Method Report

The method report contains the information and parameters of the current method:

<b>Method file</b>	The method file name.
<b>Information</b>	The contents of the Method Information field of the Method Options and Information dialog box.
<b>Operator</b>	The Operator Name when the method was set up or modified.
<b>Product</b>	The Agilent ChemStation.

The Spectrophotometer parameters are extracted from the Instrument Parameters dialog box:

<b>Instrument</b>	The name of the instrument, from the configuration file.
<b>Acquisition range</b>	The instrument acquisition range from the Instrument Parameters dialog box.
<b>Integration Time</b>	The instrument integration time from the Instrument Parameters dialog box.
<b>Std Deviation</b>	Standard deviation is always Off.

The Data Analysis parameters are extracted from the parameters dialog box for the current task; some of the parameters reported depend on the task:

<b>Data Type</b>	<b>(All Tasks)</b> The data type from the parameters dialog box for the current task.
<b>Display spectrum</b>	<b>(All Tasks)</b> The limits of spectral display from the parameters dialog box for the current task.
<b>Used Wavelength</b>	<b>(Fixed Wavelength and Quantification)</b> The contents of the Used Wavelength(s) field(s) of the parameters dialog box for the current task.
<b>Background Correction</b>	<b>(Fixed Wavelength and Quantification)</b> The contents of the Background Correction field(s) of the parameters dialog box for the current task.
<b>Find up to</b>	<b>(Spectrum/Peaks)</b> Two lines showing the selected number of peaks and valleys taken from the Spectrum/Peaks Parameters dialog box.
<b>Equation</b>	<b>(Ratio/Equation)</b> The name and formula of the equation from the Equation Parameters dialog box.
<b>Where</b>	<b>(Ratio/Equation)</b> The explanation of the terms of the equation.

## Results Report

The results report contains a header section with information about the method and data files, a graphical section and a results table. The graphical section and results table correspond with the Samples view for the selected task.

The header information consists of:

<b>Method file</b>	The method file name.
<b>Information</b>	The contents of the Method Information field of the Method Options and Information dialog box.
<b>Data File</b>	The data file name (including the full path name) and the date and time of creation.

In addition, the Results report for the Quantification task includes a summary of the calibration results:

<b>Analyte name</b>	The analyte name taken from the Quantification Parameters dialog box.
<b>Calibration equation</b>	The calibration equation calculated using the selected calibration curve type from the spectral data values extracted from the standard spectra.
<b>Calibrated at</b>	The date, time and operator name when the calibration was performed.

The last line of the report contains the current operator's name and a space for the operator's signature.

## Automation Reports

The automation reports comprise an Automation Method report and an Automation Results Report.

### Automation Method Report

The automation method report is a summary of the Automation Table. It contains the following information:

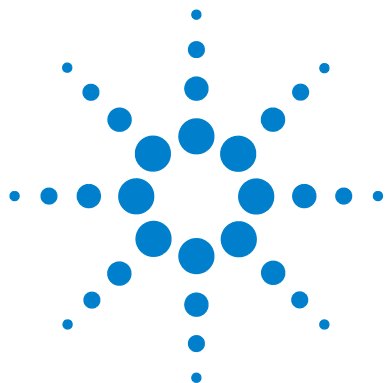
<b>Operator</b>	The name of the automation operator.
<b>Method file</b>	The automation method file name.
<b>Measure Blank</b>	The blank measurement sequence, taken from the Automation Setup dialog box.
<b>Measure Standard</b>	The standards and their concentrations, taken from the Automation Setup dialog box.
<b>Measure Control</b>	The control samples, their concentrations and the maximum permitted error, taken from the Automation Setup dialog box.
<b>Measure Samples</b>	The seed name of the samples, the number of samples and their dilution factor, taken from the Automation Setup dialog box.
<b>Measurement sequence</b>	The measurement sequence table, equivalent to the Automation Measurement Sequence dialog box.

### Automation Results Report

The automation results report contains an appropriate Results Report (see “[Results Report](#)” on page 55) for each sample in the automated sequence. In addition, statistics of the sample results can be calculated:

- average value,
- minimum value,
- maximum value,
- standard deviation,
- % relative standard deviation.





## 7 Interactive Math Functions

Unitary Operations 58

Binary Operations 64



## Unitary Operations

The unitary mathematical functions operate on single spectra. If more than one spectrum is selected, the function operates on all selected spectra individually. If no spectra are selected, the operation is aborted and an error message is displayed.

### Absorbance

Absorbance is the default method of spectral storage in the Agilent ChemStation. The Absorbance function uses logarithm and scalar multiply functions to transform transmittance spectra into absorbance spectra using [Equation 20](#). If the data are already absorbance, no processing is performed.

$$A = -\log_{10}\left(\frac{T}{100}\right) \quad (20)$$

where

$A$  is absorbance

$T$  is transmittance in percent

The variances of the spectrum (if available) are transformed by [Equation 21](#):

$$\text{var}(A) = \left(\frac{1}{T \cdot \ln 10}\right)^2 \text{var}(T) \quad (21)$$

Variance data are displayed as standard deviation data in the Tabular Data of Spectrum window. The availability of variance data depends on the integration time, set in the Spectrophotometer Parameter dialog box. Variance data are not available for integration times of less than 0.2 seconds .

## Transmittance

The Transmittance function uses exponential, reciprocal and scalar multiply functions to transform absorbance spectra into transmittance spectra using [Equation 22](#). The transmittance spectra are placed in the math result register.

$$T = 100 \cdot 10^{-A} \quad (22)$$

The variances, if available, are transformed by [Equation 23](#):

$$\text{var}(T) = (100 \cdot \ln 10 \cdot 10^{-A})^2 \cdot \text{var}(A) \quad (23)$$

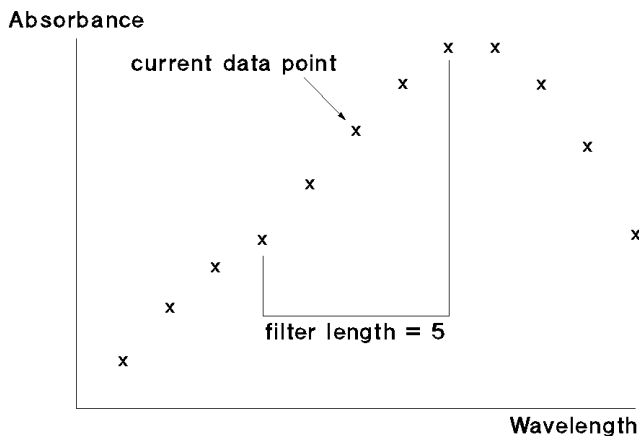
All additional information, such as annotations, are preserved unchanged in the transmittance spectrum.

## Derivative

The derivative function calculates the derivative of the data points (y-values) in the spectrum using a Savitsky-Golay algorithm and places the resulting spectrum in the math result register.

### Savitsky-Golay Algorithm

The Savitsky-Golay algorithm uses the Derivative Order, Filter Length and Polynomial Degree from the Derivative Parameter dialog box. For each data point in the spectrum, the calculation takes a set of data points equal to the filter length around the current data point, fits a curve of the specified polynomial degree, using a least squares fit. The fitted curve is then used to calculate the new value for the current data point, and the derivative of that point:



**Figure 7** Filter length in the Savitsky-Golay algorithm

For each y-value,  $y_i$ ,

$$\text{deriv}(y_i) = \sum_{kj} C_{kj} \cdot y_{i+j-1} \quad (24)$$

where

$i$  is 1 ... data points-(filter length-1)

$j$  is 1 ... filter length

$k$  is 1 for smoothing, 2 for derivative

$\text{deriv}(y_1)$  corresponds to the  $\left(\frac{(\text{filter length}-1)}{2} + 1\right)$  th value. For example, if *filter length* is 5, then  $\text{deriv}(y_1)$  becomes  $y_3$ . For this reason, the length of the spectrum is reduced by (*filter length* - 1) values;

$\left(\frac{(\text{filter length}-1)}{2}\right)$  values at the beginning of the spectrum and

$\left(\frac{(\text{filter length}-1)}{2}\right)$  values at the end of the spectrum are not processed. In

Equation 24,  $C$  is the coefficient matrix:

$$C = N^{-1} \cdot F^T \quad (25)$$

where

$N^{-1}$  is the inverse of  $N$ , the product of  $F^T$  and  $F$

$F^T$  is the transpose of  $F$ , the matrix of the powers of the polynomials

The matrix of the powers of the polynomials is generated using Equation 26:

$$F_{ij} = k^{(j-1)} \quad (26)$$

where

$i$  is 1 ... filter length

$j$  is 1... degree +1

$k$  is  $i - \frac{\text{filter length} - 1}{2} - 1$

The y-values are multiplied by the reciprocal of the wavelength step at the end of the calculation:

$$y_i = \frac{y_i}{\text{step}} \quad (27)$$

where

*step* is the increment of the equidistant x-axis

For each variance value,  $\text{var}(y_i)$ ,

$$\text{deriv}(\text{var}(y_i)) = \sum_{kj}^2 C_{kj}^2 \cdot \text{var}(y_{i+j-1}) \quad (28)$$

where

$C$  is the coefficient matrix

$i$  is 1 ... *data points* - (*filter length* - 1)

$j$  is 1 ... *filter length*

$k$  is 1 for smoothing, 2 for derivative

The variance values are multiplied by the square of the reciprocal of the step at the end of the calculation:

$$\text{var}(y_i) = \frac{\text{var}(y_i)}{\text{step}^2} \quad (29)$$

If one of the values needed for the calculation is invalid, the resulting y-value or variance value is invalid.

All additional information, such as annotations, are preserved unchanged in the derivative spectrum.

## Scalar Add

The scalar add function adds a constant value to each of the data points (y-values) in the spectrum and places the resulting spectrum in the math result register.

$$y_{\text{new}} = y + C \quad (30)$$

The scalar add function can be used to subtract a constant value by using a negative constant.

The variances (if available) and all other additional information, such as annotations, are preserved unchanged in the resulting spectrum.

## Scalar Multiply

The scalar multiply function multiplies each of the data points (y-values) in the spectrum by constant value and places the resulting spectrum in the math result register.

$$y_{\text{new}} = y \times C \quad (31)$$

The scalar multiply function can be used to divide by a constant value by using the reciprocal of the desired divisor,  $\frac{1}{C}$ .

The variances (if available) are multiplied by the square of the constant value:

$$\text{var}(y_{\text{new}}) = \text{var}(y) \times C^2 \quad (32)$$

All other additional information, such as annotations, are preserved unchanged in the resulting spectrum.

## Binary Operations

The binary mathematical functions, add and subtract, require two spectra for their operation. If no spectra are selected, or more than two spectra are selected, the operation is aborted and an error message is displayed.

### Add

The add function adds two spectra together and places the result in the math result register. The spectrum selected first (spectrum A) is taken as the model and provides the wavelength range and resolution for the resulting spectrum. Spectrum A is first copied into the math result register, then the y-values (for example absorbance) from the second selected spectrum (spectrum B) are added to the y-values of the spectrum in the math result register as follows:

#### Spectra of Different Wavelength Resolutions

If the x-values of spectrum A do not completely agree with those of spectrum B

- the y-values of spectrum B are interpolated before adding them to the y-values of the resulting spectrum when the interval of the x-value in spectrum A is less than that of spectrum B.
- the y-values at intermediate x-values in spectrum B are ignored when the interval of the x-value of spectrum A is greater than that of spectrum B, and only the y-values from spectrum B at the x-values corresponding to spectrum A are added to the y-values of the resulting spectrum.



### **Spectra of Different Wavelength Ranges**

If the x-range (wavelength range) of spectrum A is greater than the x-range of spectrum B, the extra y-values in spectrum A remain unchanged in the result.

If the x-range of spectrum A is less than the x-range of spectrum B, the extra y-values in spectrum B are ignored.

If there is no overlap between the x-ranges of the spectra, spectrum A remains unchanged.

### **Variances**

If variances are available in both spectra, the values from the spectrum B are added to those in spectrum A in the same way as for the y-values.

If only spectrum A contains variances, the values remain unchanged in the result.

If only spectrum B has variances, they are ignored.

Additional information, such as annotations, are taken solely from spectrum A; all such items from spectrum B are ignored.

## Subtract

The subtract function subtracts one spectrum from another and places the result in the math result register. The spectrum selected first (spectrum A) is taken as the model and provides the wavelength range and resolution for the resulting spectrum. Spectrum A is first copied into the math result register, then the y-values (for example absorbance) from the second selected spectrum (spectrum B) are subtracted from the y-values of the spectrum in the math result register as follows.

### Spectra of Different Wavelength Resolutions

If the x-values of spectrum A do not completely agree with those of spectrum B:

- the y-values of spectrum B are interpolated before subtracting them from the y-values of the resulting spectrum when the interval of the x-value in spectrum A is less than that of spectrum B, and
- the y-values at intermediate x-values in spectrum B are ignored when the interval of the x-value of spectrum A is greater than that of spectrum B, and only the y-values from spectrum B at the x-values corresponding to spectrum A are subtracted from the y-values of the resulting spectrum.

### Spectra of Different Wavelength Ranges

If the x-range (wavelength range) of spectrum A is greater than the x-range of spectrum B, the extra y-values in spectrum A remain unchanged in the result.

If the x-range of spectrum A is less than the x-range of spectrum B, the extra y-values in spectrum B are ignored.

### Variances

If variances are available in both spectra, the values from the spectrum B are added to those in spectrum A in the same way as for the Add function (see “Add” on page 64).

If only spectrum A contains variances, the values remain unchanged in the result.

If only spectrum B has variances, they are ignored.

Additional information, such as annotations, are taken solely from spectrum A; all such items from spectrum B are ignored.

## **7 Interactive Math Functions**

### **Binary Operations**



## 8 Configuration and Methods

System Configuration	70
The Configuration File	72
Methods	73
The ChemStation.ini File	77
The Directory Structure	78



## System Configuration

The configuration of the PC hardware and the Agilent ChemStation software to communicate with the Agilent 8453 spectrophotometer and its accessories has three aspects.

- Configuration of the communications between the Agilent ChemStation and the other devices (spectrophotometer, temperature controller) that are connected with and controlled by it. This process is carried out using the Configuration Editor.
- Internal configuration of the software using the commands from the Config menu.
- Configuration of the sampling system using the commands from the Instrument menu.

### Configuring the Hardware

The Configuration Editor, which is a stand-alone program, is used to configure the Agilent ChemStation for the spectrophotometers and other GPIB accessories that are connected with it. The Configuration Editor sets up the communication pathways that allow the Agilent ChemStation to control the spectrophotometer and other accessories that communicate via GPIB or LAN. The Configuration Editor builds the configuration information into the ChemStation.ini file located in the *windows* directory of your Microsoft® Windows™ operating system installation.

The Editor is also used to configure the UV-visible ChemStation software's color scheme, and can be used to define the default paths for the Agilent ChemStation software's files; configuration information for both the color scheme and paths are also included in the ChemStation.ini file.

#### NOTE

You can also redefine paths for the data files, method files and automation files (automation table and sample table) from within the Agilent UV-visible ChemStation software

The Agilent 8453 spectrophotometer and Agilent ChemStation undergo a dialog during start-up that results in the automatic configuration of the spectrophotometer. The following information is passed from the spectrophotometer to the Agilent ChemStation:

- The instrument type, firmware revision number and serial number
- The sampling interval
- The time for which the instrument has been switched on.
- The lamp condition (on or off)
- The spectrophotometer status
- The availability of a blank spectrum

The Agilent ChemStation downloads the spectrophotometer parameters of the current method to the spectrophotometer when the method is loaded during start-up.

## The Configuration File

The configuration file controls the system set-up at start-up. All information relating to the configuration of the Agilent ChemStation software is stored in the configuration file, and the information is transferred into the configuration register when the Agilent ChemStation is started. The file is updated (and the current configuration saved) by overwriting the current contents of the file with the contents of the configuration register when the Save Configuration check box is selected when the Agilent ChemStation software is closed down.

When you save the configuration using the Save Configuration check box, you also save the current size and position of all windows and tables in all views.

The configuration register contains the following information:

<b>User interface parameters</b>	Definitions of the sizes and positions of all graphics windows.
<b>Table templates and descriptions</b>	Definitions of the format and contents of all tables.
<b>System variables</b>	The current sample name, whether the method has changed or not, system messages: information and error messages.
<b>Acquisition information</b>	Information about sampling systems, and the Configuration of Verification table.
<b>Report information</b>	Information for the formatting of reports.



# Methods

A method is a set of parameters that defines the analysis of a sample. A method can define a simple analysis, such as measuring the sample in the cell and displaying the absorbance spectrum, or a complex one, such as introducing a sample using the specified sampling system, measuring the sample, performing spectral processing steps, calculating a result using a pre-defined equation and printing a report.

## The Structure of Methods

The method definition optionally includes any or all of the following parameters:

- a description of the method.
- instrument and acquisition parameters:
  - parameters to prepare the configured sampling system to collect the sample.
  - the sample temperature and stirrer parameters of the Agilent 89090A temperature controller (if fitted and configured).
  - the acquisition parameters of the spectrophotometer.
  - the name of the data file in which the measured spectra will be stored automatically.
  - the parameters for the user interface display.
- the data analysis parameters:
  - the spectral processing parameters that are applied to the measured spectra.
  - parameters for the extraction of wavelength data.
  - the parameters necessary for the calculation of the final result, for example an equation or quantification parameters, depending on the method.

The contents of the method definition depends on the settings defined by the user and the functionality available in the selected task.

## Method Files

Method files are stored in a subdirectory METHODS of the instrument directory (1 for example). They have the extension .M.

### The Status of Methods

Methods can exist in two states:

- as the **current method**, which is the method that is loaded into memory,
- as a **stored method** on disk. The current method can be stored on disk by selecting Save Method As from the File menu. Any stored method can replace the current method in memory by selecting Load Method...from the File menu and specifying the method to be loaded.

### The Contents of the Method

The definition of the current method is held in a register (see “Registers” on page 20 for a description of registers), which contains the following information:

- the date and time of the last update of the method.
- the product number and software revision number.
- the contents of the Method Information field of the Method Options and Information dialog box.
- The state of the Autosave Spectra to File check box and the contents of the adjacent field in the Method Options and Information dialog box.
- a table that is the core of the method containing the information that defines the method parameters:
  - data analysis parameters,
  - spectrophotometer parameters,
  - temperature controller parameters,
  - sampling system parameters,
  - report parameters,
  - automation parameters.

## On Using a Method

When a method is loaded, the system is set up using the method parameters. The Measure command causes the method to be executed. On Using a Method shows the processes that occur, and the information that is input at each stage when a complete method is executed.

### Sample Measurement

- 1 The configured sampling system collects the sample with the conditions specified in its parameter dialog box.
- 2 If the Wait for Temperature Ready check box in the sampling system's Setup dialog box is selected, the Agilent ChemStation checks the status of the Agilent 89090A Peltier temperature control accessory.
- 3 When the status of the temperature controller is Ready, the Agilent ChemStation initiates a measurement by the spectrophotometer of the sample in the cell using the parameters specified in the Spectrophotometer Parameters dialog box.
- 4 If the method is used in an Automation, and the Autosave Spectra to File check box in the Method Options and Information is selected, the spectra are appended to the defined file.

### Data Analysis

- 1 The measured spectra undergo data analysis.

The sample spectra are processed using the parameters defined in the parameters dialog box for the selected task.

The data for the wavelength results are extracted from the processed spectra and the wavelength result is calculated.

If the Ratio/Equation task has been selected, the analysis result is calculated from the wavelength result using the equation parameters.

If the Quantification task has been selected, the analysis result is calculated from the wavelength result using the quantification parameters.

### Printing the Report

- 1** The report is formatted according to the parameters in the Configure Report dialog box and printed according to the parameters in the Printer Control dialog box.

## The ChemStation.ini File

During installation of the software and configuration of the system, three or more sections are added to the ChemStation.ini file:

<b>[PCS]</b>	contains the information about the instruments that are connected and the communications parameters.
<b>[PCS,n]</b>	contains the details of screen colors, data paths and file names for instrument number n. Each configured spectrophotometer has an entry, for example [PCS,1], [PCS,2] and so on.
<b>[HPCHEM]</b>	contains the access level and the encrypted password.

### CAUTION

You must not change any of the entries in these sections of the ChemStation.ini file. Any changes will give rise to unpredictable behavior, and may prevent the UV-visible ChemStation software from starting up.

---

## The Directory Structure

During installation of the Agilent ChemStation software, a directory structure is created that has a root directory with a minimum of four subdirectories. The default name for the main directory is Chem32; this directory and the Chem32\SYS and Chem32\UVEXE directories are appended to the PATH system variable of your operating system's environment variables.

If you entered different name for the root directory of your installation, the name you specified is used in place of Chem32, Chem32\SYS and Chem32\UVEXE in the PATH variable.

For an analytical system with one spectrophotometer, Chem32 has four subdirectories:

<b>UVEXE</b>	contains software for the operation of the Agilent ChemStation software. UVEXE has five subdirectories:
<b>HELPENU</b>	contains the on-line Help files. These files are necessary for the context-sensitive Help facilities of the Agilent ChemStation software.
<b>LANGUAGE</b>	will contain files for local language support of the Agilent ChemStation software.
<b>PICTURES</b>	contains the files for the graphical user interface. These files are also necessary for the operation of the Agilent ChemStation software.
<b>SYSMACRO</b>	contains the system macro files. These files are necessary for the operation of the Agilent ChemStation software.
<b>USERMAC</b>	contains user-generated macro files.

You must not delete any of the files in the UVEXE or SYSMACRO subdirectories. If any of these files are missing or corrupted, the operation of your Agilent ChemStation software will be either unpredictable or impossible.

**1** contains the parameter files and data files for the analytical system configured as number 1. The files are held in five subdirectories.

<b>AUTOMAT</b>	contains the saved automation tables.
<b>DATA</b>	contains the sample spectra that have been saved on disk.
<b>DIAGNOSE</b>	contains the results of verification tests.
<b>METHODS</b>	contains the saved method files.
<b>REPORTS</b>	contains the report files that have been saved on disk.
<b>STDS</b>	contains the standard spectra that have been saved on disk.

For each additional instrument configured the above mentioned set of subdirectories is created. The root of the additional instruments is called 2,...4. A maximum of 4 instruments can be configured.

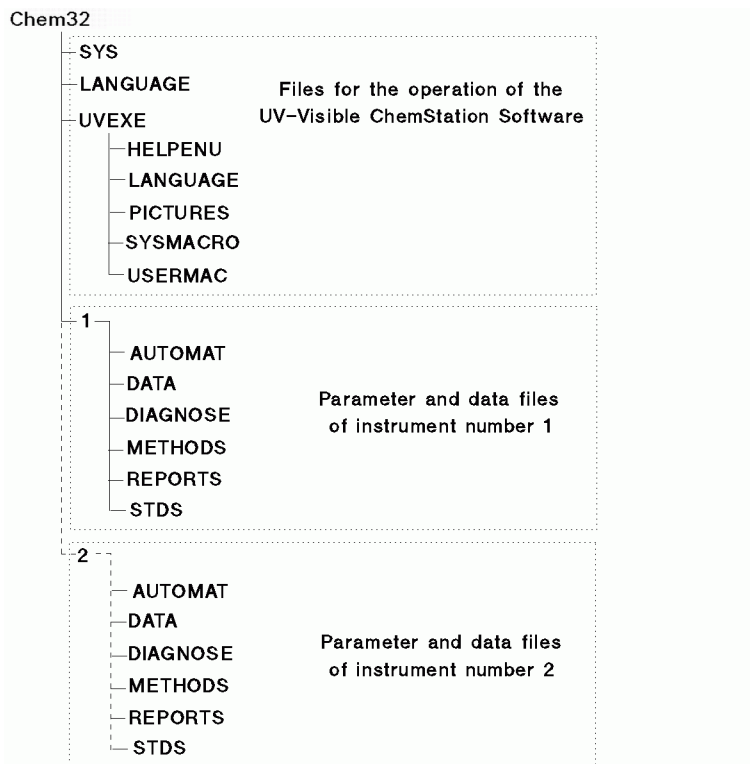
**SYS** contains software for the operation of the Agilent ChemStation software.

## CAUTION

You must not delete any of the files in the SYS subdirectory. If any of these files are missing or corrupted, the operation of your Agilent ChemStation software will be either unpredictable or impossible.

**LANGUAGE** will contain files for local language support of the UV-visible ChemStation software.

Figure 8 shows the directory structure of the Agilent ChemStation software.



**Figure 8** Directory Structure of the Agilent ChemStation Software

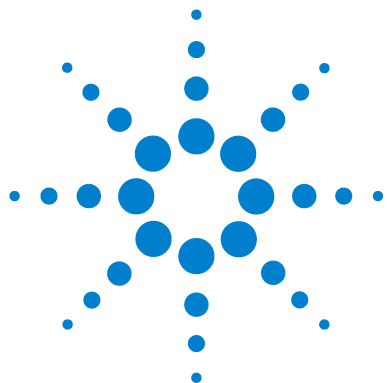


## File Formats

All standard files associated with the Agilent ChemStation, both software and data, are in binary format, and therefore cannot be accessed (neither viewed nor edited) using standard text editing programs. This ensures compatibility with the guidelines of good laboratory practice (GLP).

When report to file is selected, the report is saved in ASCII format with the extension .TXT; report graphics are saved as Windows metafiles (binary format) with the extension .WMF.





## 9 Verification

Configuration of Verification 84

Verification Tests 85

Spectrophotometer Selftests 94

Flow Test 95



## Configuration of Verification

The information about the spectrophotometer and the filters used for the verification that you enter into the Instrument Verification Parameter dialog box is transferred into the Configuration of Verification table and can be stored in the configuration file (see “[System Configuration](#)” on page 70) by selecting the Save Configuration check box in the Close dialog box when you exit from the Agilent ChemStation software. There is no necessity to edit the configuration parameters thereafter unless you change one of the verification filters.

The other information in the Configuration of Verification table is transferred into the table automatically. The values are dependent on the spectrophotometer that is connected; to conform to the requirements of good laboratory practice (GLP), these values cannot be edited.

## Verification Tests

### NOTE

The instrument should be allowed to warm up for a minimum of 45 minutes before running a verification.

---

### Wavelength Accuracy

An absorbance spectrum of an appropriate wavelength calibration standard is measured using 0.5 second integration time. This spectrum is converted into transmittance and the wavelength of specified peak minima are determined with the help of a spline function. The standards, reference wavelengths and specification used for the wavelength accuracy test are shown in [Table 9](#).

**Table 9** Parameters for the Wavelength Accuracy Test

Spectrophotometer	Filter	Wavelengths Used (nm)	Specification
Agilent 8453 190–1100 nm	NIST 2034 holmium oxide solution	241.10, 249.92, 278.06, 287.33, 333.42, 345.48, 361.23, 385.76, 416.45, 451.30, 467.88, 485.31, 536.80, 640.68*	±0.5 nm

\* The exact wavelengths of the bands varies with the spectral bandwidth (SBW) of the instrument. The Agilent 8453 has a nominal SBW of 1.5 nm over the wavelength range covered by holmium oxide solution (240–650 nm) determined either by the “Effective Bandwidth” method proposed by NIST<sup>1</sup> or by the toluene in hexane test proposed by the European Pharmacopoeia<sup>2</sup> (note that the actual typical value for 269/266 nm ratio for the Agilent 8453 is 1.75 which is equivalent to 1.45 nm SBW, whereas the specifications for the Agilent 8453 give a minimum value of 1.6 for the ratio). The actual wavelength values used for the Agilent 8453 are obtained by linear interpolation between the 2 nm and 1 nm values provided by NIST<sup>4</sup> to obtain values for 1.5 nm SBW. The validity of this approach has been confirmed by NIST<sup>3</sup>.

**References:**

- 1** NBS Special Publication 260-66, Didymium Glass Filters for Calibrating the Wavelength Scale of Spectrophotometers, Venable W.H., Eckerle, K.L., October, 1979, p.70.
- 2** 2. Pharmeuropa, Guide for the Technical Content of Monographs, Council of Europe, pp. 14- 15, 1993.
- 3** 3. Private communication, John Travis, NIST, 10 March, 1997.
- 4** 4. NIST Certificate, Standard Reference Material 2034, Holmium Oxide Solution Wavelength Standard from 240 to 650 nm, Series No. 95, 1995.

The calculation includes an additional acceptance tolerance of  $\pm 0.1$  nm for the NIST reference material and  $\pm 0.2$  nm for a holmium oxide solution because of the uncertainty of determining the true wavelength position of the peak. Upper and lower limits for the position of the measured peak are calculated from the used wavelength, the peak detection uncertainty and the specification:

$$\lambda_{\text{upper}} = \lambda_{\text{used}} + \lambda_{\text{specification}} + \lambda_{\text{uncertainty}} \quad (33)$$

and

$$\lambda_{\text{lower}} = \lambda_{\text{used}} + \lambda_{\text{specification}} + \lambda_{\text{uncertainty}} \quad (34)$$

The detected peak must lie within these two limits:

$$\lambda_{\text{lower}} \leq \lambda_{\text{measured}} \leq \lambda_{\text{upper}} \quad (35)$$

## Photometric Accuracy

The NIST SRM 930 E 10% transmittance, neutral density glass standard is used for the photometric accuracy test. The tolerance limits for the calibration value of the filter are increased by 1% per year (see the NIST documentation that was delivered with your filter), and this is allowed for in the calculation.

A spectrum is measured using the photometric accuracy filter with an integration time of 0.5 seconds at 440.0 nm, 465.0 nm, 546.1 nm, 590.0 nm and 635.0 nm.

$$T_{\text{aging}} = \left( \frac{N_{\text{calib}}}{12} \right) \cdot T_{\text{nom}} \cdot 1\% \quad (36)$$

where

$T_{\text{nom}}$  is the nominal transmittance of the photometric accuracy filter

$N_{\text{calib}}$  is the age of the filter in months

$T_{\text{aging}}$  is the aging tolerance of the filter in transmittance

$$A_{\text{aging}} = \log(e) \cdot \frac{T_{\text{aging}}}{T_{\text{nom}}} \quad (37)$$

where

$T_{\text{aging}}$  is the aging tolerance of the filter in transmittance

$e$  is the Euler constant

Substituting Equation 37 into Equation 36 gives Equation 38:

$$A_{\text{aging}} = 0.00036191 \cdot N_{\text{calib}} \quad (38)$$



The permitted error for the verification is then:

$$\varepsilon = \sqrt{A_{\text{aging}}^2 + \varepsilon_{\text{inst}}^2} \quad (39)$$

where

$\varepsilon_{\text{inst}}$  is the instrument tolerance

Finally, an upper and lower limit for the measured absorbance is calculated from:

$$A_{\text{upper}} = -\log(T_{\text{nom}}) + \varepsilon \quad (40)$$

$$A_{\text{lower}} = -\log(T_{\text{nom}}) - \varepsilon \quad (41)$$

The instrument passes the test if the measured absorbance,  $A_{\text{meas}}$  is within the upper and lower limits:

$$A_{\text{lower}} \leq A_{\text{measured}} \leq A_{\text{upper}} \quad (42)$$

An alternative tests is using a potassium dichromate solution (57–63 mg) as specified by the European Pharmacopoeia 5<sup>th</sup> edition 2005 dissolved in 1000 ml and in 100 ml (~60 mg/L and ~600 mg/L):

**Table 10** Parameters for the Agilent 8453 Photometric Accuracy Test

Spectrophotometer	Filter	Wavelengths Used	Photometric Accuracy Limit
Agilent 8453 190–1100nm	Potassium dichromate solution in 0.01 N sulfuric acid dissolved in 1000 ml (about 60 mg/L)	235 nm	0.748 ±0.01 AU
		257 nm	0.868 ±0.01 AU
		313 nm	0.292 ±0.01 AU
		350 nm	0.644 ±0.01 AU
Agilent 8453 190–1100nm	Potassium dichromate solution in 0.01 N sulfuric acid dissolved in 100 ml (about 600 mg/L)	430 nm	0.954 ±0.012 AU

The absorbance values are normalized by the weight of potassium dichromate used (about 60 mg/L):

$$\text{Normalized value} = \text{measured value} \times \frac{60.06}{\text{weight (mg)}} \times \frac{1}{\text{path length (cm)}}$$

The absorbance values are normalized by the weight of potassium dichromate used (about 600 mg/L):

$$\text{Normalized value} = \text{measured value} \times \frac{600}{\text{weight (mg)}} \times \frac{1}{\text{path length (cm)}}$$

## Stray Light

The stray light is measured with an integration time of 0.5 seconds using a cut-off filter that transmits light at longer wavelengths and blocks light at shorter wavelengths. The transmittance at one or two wavelengths is used to check the stray light.

**Table 11** Parameters for the Stray Light Test

Filter	Wavelength(s) Used	Stray Light Limit
NaNO <sub>2</sub> (50 g/l)	340 nm	<0.03%
NaI (10 g/l)	220 nm	<0.05%
KCl (1.2%)	198 nm	<1%

The transmittance at the specified wavelengths must be lower than the stray light limit for the instrument to pass the wavelength accuracy test:

$$T_{\text{meas}} < \text{Stray Light Limit} \quad (43)$$

## Resolution

Resolution is measured by taking a blank spectrum on air (with nothing in the light path), then measuring the ratio of the absorbance maximum at about 269 nm and the absorbance valley at about 266 nm in a 0.02% v/v solution of toluene in hexane. The resolution specification is:

$$\frac{\text{Abs}_{\text{max}} (\sim 269)}{\text{Abs}_{\text{min}} (\sim 266)} > 1.6 \quad (44)$$

# Noise

Noise is measured by taking spectra of air (with nothing in the light path) with an integration time of 0.5 seconds over a run time of 60 seconds. An RMS calculation of the noise is made at a single wavelength. Noise limits are shown in [Table 12](#).

**Table 12** Parameters for the Noise Verification Test

Wavelength Used	Noise Limit
500 nm	<0.0002 AU

The RMS noise must be less than the specified value for the instrument to pass the noise test:

$$\sqrt{\frac{\sum (R - \bar{R})^2}{(n - 1)}} < \text{Noise Limit} \quad (45)$$

where

$R$  is the measured absorbance value

$\bar{R}$  is the average of the absorbance values to 5 points either side of  $R$  in time

$n$  is the total number of absorbance values used

## Baseline Flatness

Baseline flatness is measured by taking a spectrum on air (with nothing in the light path) using an integration time of 0.5 seconds. An RMS calculation of the spectrum is made over the wavelength range of the instrument, as shown in [Table 13](#).

**Table 13** Parameters for the Baseline Flatness Test

Wavelength Range Used	Baseline Flatness Limit
190–1100nm	<0.001 AU

The RMS value must be less than the specified value for the instrument to pass the baseline flatness test:

$$\sqrt{\frac{\sum (R - \bar{R})^2}{(n - 1)}} < \text{Baseline Flatness Limit} \quad (46)$$

where

$R$  is the measured absorbance value

$\bar{R}$  is the average of the absorbance values over the wavelength range

$n$  is the total number of absorbance values used

## Stability

Stability is measured by taking spectra on air (with nothing in the light path) with an integration time of 0.5 seconds and a cycle time of 5 seconds over a period of one hour. The stability is the difference between the maximum and minimum absorbance readings at a specified wavelength as shown in [Table 14](#).

**Table 14** Parameters for the Stability Verification Test

Wavelength Used	Stability Limit
340 nm	<0.001 AU

The stability must be less than the specified value for the instrument to pass the stability test:

$$A_{\max} - A_{\min} < \text{Stability Limit} \quad (47)$$

The room temperature should remain constant to  $\pm 1$  °C during the stability test.

# Spectrophotometer Selftests

The spectrophotometer diagnostic starts a series of self-tests that are essentially similar to the power-on self-tests (POST) carried out when the spectrophotometer is turned on. The diagnostic cycles through the self-tests continuously until it is aborted by choosing the Stop Spectrophotometer Diagnostic button.

<b>Electronics self tests</b>	The spectrophotometer electronics (CPU, RAM, ROM, &c.) are tested.
<b>Dark Current test</b>	Checks the residual dark current in the diode array when the shutter is used to block any incident light.
<b>Lamp Intensity test</b>	Checks the lamp intensity over the whole wavelength range against minimum limits.
<b>Wavelength Accuracy test</b>	Uses the two deuterium emission lines at 486 nm and 656.1 nm to check the wavelength accuracy.
<b>RMS Noise test</b>	Checks the RMS noise over 60 seconds against a maximum limit.
<b>RMS Baseline</b>	Checks the baseline flatness over the wavelength range of the instrument.

# Flow Test

The Flow Test diagnostic for the sipper and autosamplers measures the absorbance at a specified wavelength as sample replaces blank medium in the flow cell. The test pumps sample for 1.5 times the Pump time (set in the sampling system’s Parameter dialog box), then plots a flow profile and calculates the estimated minimum pump time for a specified percentage absorbance to be reached. Default instrument parameters for the flow test are:

**Table 15** Default Instrument Parameters for the Flow Test Diagnostic Test

Integration Time	Gain	Cycle Time	Run Time	Wavelength	Percent
0.5 s	Auto	1 s	Pump time × 1.5	340 nm	99.5

At the end of the run, the averages of the first two and last two measurements are calculated; the difference between the two averages gives the 100% difference in absorbance:

$$A_{0\%} = \frac{A_1 + A_2}{2}$$

and

$$A_{100\%} = \frac{A_{n-1} + A_n}{2}$$

where

$A$  is absorbance

$n$  is the number of data points

The absolute absorbance value for the user-specified Percent objective is calculated by [Equation 47](#):

$$A_{\text{user}\%} = \frac{(A_{100\%} - A_{0\%}) \cdot \text{Percent}}{100} + A_{0\%} \quad (48)$$

where

*Percent* is the user-specified Percent objective

The flow profile is scanned to find the time,  $T_E$ , at which the measured absorbance exceeds the absolute absorbance for the user-specified Percent objective,  $A_{\text{user}\%}$ . This is the Estimated Minimum Pump Time.



# Index

## A

absorbance, [23, 34, 58](#)  
  spectrum, [13](#)  
accuracy  
  wavelength, [94](#)  
acquisition  
  parameters, [73](#)  
  range, [53](#)  
add, [64](#)  
Agilent 8453  
  optical system, [11](#)  
analog-to-digital converter, [11](#)  
analyte, [23, 41](#)  
  name, [55](#)  
analytes table, [23](#)  
annotation limit, [52](#)  
automation  
  method report, [51, 56](#)  
  parameters, [74](#)  
  results report, [51, 56](#)  
  table, [51, 56, 79](#)  
autosampler, [95](#)  
autosave, [74](#)

## B

background correction, [35, 54](#)  
baseline flatness, [92, 94](#)  
Beer-Lambert law, [41](#)  
binary functions, [64](#)  
blank  
  measurement sequence, [56](#)  
  spectrum, [20, 71](#)

## C

calibration, [16, 41, 42](#)  
  coefficient, [17, 42](#)  
  coefficient k, [41](#)  
  curve, [42, 55](#)  
  curve fits, [45](#)  
  curve types, [42](#)  
  data, [15](#)  
  diagnostics, [21](#)  
  results, [48, 55](#)  
  standards, [44](#)  
  wavelength, [14](#)  
ChemStation.ini, [70](#)  
ChemStation.ini file, [70, 77](#)  
coefficient  
  calibration, [17, 42](#)  
  correlation, [49](#)  
  matrix, [61](#)  
color configuration, [70](#)  
colors, [70](#)  
comment, [23](#)  
communication, [70](#)  
  pathways, [70](#)  
configuration, [20, 70](#)  
  color, [70](#)  
  editor, [70](#)  
  file, [72, 84](#)  
  hardware, [70](#)  
  register, [72](#)  
  software, [70](#)  
  spectrophotometer, [71](#)  
  system, [20, 70](#)  
  temperature controller, [70](#)  
configuration of verification, [84](#)  
  table, [72](#)  
control samples, [56](#)  
correlation coefficient, [49](#)

current method, [17, 51, 53, 71, 74](#)

## D

dark current, [13](#)  
  correction, [12](#)  
  test, [94](#)  
data  
  block, [21, 23, 24](#)  
  flow, [15](#)  
  raw, [10](#)  
  structure, [23](#)  
  type, [23, 54](#)  
data analysis, [75](#)  
  parameters, [20, 54, 74](#)  
data file, [79](#)  
  name, [55, 73](#)  
date, [23, 55, 74](#)  
default, [70](#)  
default path, [70](#)  
derivative, [27, 34, 60](#)  
  order, [60](#)  
  parameters, [60](#)  
dilution factor, [40, 56](#)  
directory structure, [78, 80](#)

## E

editor  
  configuration, [70](#)  
electronics self tests, [94](#)  
equation, [54](#)  
  evaluation, [40](#)  
  name, [54](#)  
  parameters, [73](#)  
error  
  %error, [48](#)  
error messages, [72](#)

## Index

evaluation, 15, 17, 21  
equation, 40  
results, 51

## F

file  
ChemStation.ini, 70  
configuration, 72, 84  
format, 81  
method, 74, 79  
filter, 11  
filter length, 27, 60  
firmware, 10, 14, 23  
revision number, 71  
firmware revision, 71  
flow  
profile, 95  
test, 95  
formula, 54  
function result, 21, 42

## G

graphical user interface files, 78  
graphics windows, 72

## H

hardware configuration, 70  
header block, 23, 24

## I

identification number, 71  
indents, 52  
instrument  
identification number, 23  
name, 53  
parameters, 20, 53, 73, 74  
type, 71  
integration time, 12, 23, 53, 58  
intensity  
lamp, 94  
spectrum, 11, 13  
intercept, 42

invalid data, 14

## L

lamp  
condition, 71  
intensity, 94  
least squares fit, 60  
least squares method, 45

## M

macro files  
system, 78  
user-generated, 78  
margins, 52  
math result, 20  
mathematical operators, 28  
maxima, 27  
measurement sequence table, 56  
method, 71, 72, 73  
description, 20, 73  
file, 74, 79  
file name, 53, 55, 56  
information, 53, 55, 74  
parameters, 74  
report, 51, 53  
minima, 27  
molar extinction coefficient, 41

## N

noise, 91, 94

## O

object, 21  
header, 21  
offset, 42  
on-line help files, 78  
operating software, 78, 79  
operator name, 23, 53, 55, 56  
optical system  
Agilent 8453, 11

## P

parameter files, 79  
parameters  
acquisition, 73  
instrument, 20, 53, 73, 74  
method, 74  
printer setup, 52  
quantification, 73  
report, 72, 74  
report configuration, 52  
sampling system, 20, 73, 74  
spectral processing, 73  
spectrophotometer, 20, 53, 74  
stirrer, 73  
temperature controller, 74  
used wavelength, 73  
password, 77  
path, 70  
name, 55  
path length, 23, 40, 41  
peaks, 27, 54  
photometric accuracy, 88  
polynomial degree, 27, 60  
printer setup parameters, 52  
printing report, 75  
product number, 74  
pump time  
estimated minimum, 95  
in flow test, 95

## Q

quadratic, 42  
quantification, 21, 41, 50  
parameters, 73  
quantification task, 41

## R

ratio/equation task, 28  
raw data, 10, 20  
reference spectrum, 12  
register, 20  
configuration, 72

report  
 configuration parameters, 52  
 files, 79  
 method, 51, 53  
 orientation, 52  
 parameters, 72, 74  
 results, 51, 55  
 residual, 48  
 resolution, 23, 90  
 wavelength, 64, 66  
 results  
 calibration, 48, 55  
 evaluation, 51  
 report, 51, 55  
 RMS noise, 91

## S

sample  
 measurement, 75  
 name, 23, 72  
 spectra, 20, 79  
 temperature, 73  
 sample-related dynamics, 15  
 sampling interval, 71  
 sampling system, 72  
 parameters, 20, 73, 74  
 Savitsky-Golay, 60  
 scalar add, 63  
 scalar divide, 63  
 scalar multiply, 58, 63  
 scalar subtract, 63  
 self-tests, 94  
 electronic, 94  
 serial number, 71  
 shutter, 11  
 single reference wavelength, 35  
 sipper, 95  
 software  
 configuration, 70  
 revision number, 74  
 solvent, 23  
 spectral data, 20  
 spectral display limits, 54

spectral processing parameters, 73  
 spectrophotometer  
 configuration, 71  
 parameters, 20, 53, 74  
 status, 71  
 spectrum/peaks task, 27  
 stability, 93  
 standard deviation, 23, 53, 58  
 of calibration, 48  
 of coefficient, 49  
 standard spectra, 20, 79  
 standards, 41, 44  
 minimum number, 43  
 statistical errors, 45  
 step, 62  
 stirrer parameters, 73  
 stored method, 74  
 stray light, 11, 90  
 correction, 12  
 subtract, 66  
 subtract average over range, 37  
 subtraction, 36  
 system  
 configuration, 20, 70  
 macro files, 78  
 messages, 72

## T

table, 21  
 format, 72  
 temperature, 23, 73  
 temperature controller  
 configuration, 70  
 parameters, 74  
 temporary registers, 21  
 text file, 51  
 three-point drop-line, 37  
 time, 23, 55, 71, 74  
 transmittance, 34, 59

## U

unitary functions, 58

unknown sample, quantification, 50  
 use wavelengths, 35  
 used wavelength parameters, 73  
 user interface display parameters, 73  
 user-generated macro files, 78

## V

valleys, 27, 54  
 variance, 12, 23, 58  
 verification test results, 79  
 view, 24  
 volume, 28, 40

## W

wavelength, 23  
 accuracy, 94  
 calibration, 14  
 range, 27, 64, 66  
 resolution, 64, 66  
 weight, 28, 40  
 window, 24





## **In This Book**

This manual describes the data processing operations of the Agilent 8453 spectrophotometer and the Agilent ChemStation for UV-visible spectroscopy. It describes the processes and transformations that the spectrophotometric data undergo between the time that they are acquired in the spectrophotometer and their output on the Agilent ChemStation display or printer. The manual is designed to enable you to follow good laboratory practice (GLP) guidelines; using the information in the manual, you will be able to understand the data processing calculations from beginning to end and perform the data evaluation manually.

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